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CONCERNING THE CONCEPT OF THE CENTRAL MOUNTAIN FOEHN

by

H.G. Koch

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CONCERNING THE CONCEPT OF THE CENTRAL MOUNTAIN FOEHN

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CONCERNING THE CONCEPT OF THE CENTRAL MOUNTAIN FOEHN

H. G. Koch

Extreme values and thermograph recordings of pairs of stations situated at equal altitude on the windward and leeward side of the Thuringian Forest are evaluated. The annual variation of the Southwest-foehn is shown to be related to the frequency of westerly weather conditions. Furthermore, the existence of a Northeast-foehn is revealed. Both wind directions may be accompanied by "true" foehn occurrences while the sky is overcast on both sides of the Forest with low cloud heights and a small but distinct temperature increase on the lee-side of the mountain range. As regards temperatures and the number of occurrences, cases are more evident when by windward cloud lifting and lee-side dissipation contrasts are more pronounced. The foehn is associated with warm fronts and, chiefly, post-cold frontal and unstable conditions, which therefore add considerably to the conventional high mountain foehn criteria. It is proposed to use the temperature and humidity differences of both mountain sides as a criterion to determine the foehn of the Central Mountains. However, the influence of fair weather upon valley and local basin conditions has to be taken into account; hence, steep slope stations are definitely preferable.

1. Introduction

Discussions concerning the foehn have recently been intensified - primarily in bioclimatology [1]. The fact that the "foehn problem" is even discussed for Northern Germany [2] and can also be observed with certainty in the Central Mountain region, even when there are no general symptoms of an orographic foehn, clearly demonstrates, on the one hand, that the concept of the "foehn" is very greatly diluted, and on the other hand a clarification of the concepts should first be provided for the mountainous regions themselves. The Central Mountains, in their

intermediate position between the high mountains and the hills or lowlands, have the disadvantage that the temperature and humidity effects, due to the small height differences, are not so strikingly manifested and, however, possess the priceless advantage of a more easy survey as to the weather events at the windward and leeward, and better monitoring of the terrain by suitable weather stations.

In regard to foehn processes in the Central Mountains, we have rather good information since the classical descriptions of Assmann from 1885 [3] and from numerous other works in reference to individual phenomena and certain effects in the wind, temperature, and humidity field. However with regard to the climatic, or long term effects of the seasonal occurrence and especially a classification of the manifold foehn-like situations, there is much which is unclear. The simple question of characterizing a foehn situation by certain criteria is very diverse for the high mountains, but for the Central Mountains it has not even been mentioned. Finally, in this connection, we must raise the question as to whether purely dynamically conditioned warmings during a cyclonal foehn can be detected under the slight altitude differerces in the Central Mountains, and whether we may in fact speak of an orographic foehn at all. In this sense, the following remarks should contribute to a solution.

The climatic effect of the Central Mountain foehn is without doubt most impressive in the precipitation distribution pattern. The numerous daily, monthly, and yearly charts provide excellent examples of this - especially under consideration of the seasonal differences. But even in regard to the temperature relationships, which represent a reliable existence criterion for the high mountain foehn, a statement as to the degree of effectiveness is very difficult. Often by means of yearly or monthly mean temperatures, the temperature excess of the affected

lee district is demonstrated by a reduction to the NN or to a common mean height. But in this way - usually employing the von Elsner gradients - large errors occur, which are to be attributed to the daily course, as well as the weather situation and local influences of the measurement positions; these themselves can hardly be eliminated in the long-term mean, or under consideration of certain frequencies of the weather conditions. However the "fair weather effect" of the valleys is responsible for unforeseeable reduction errors. In this sense, e.g., the Thuringian stations of Grossbreitenbach and Oberhain (both prior to 1891), often cited from the "climate zone" for the demonstration of a leeward warming, misleadingly reveal a temperature excess which is much too high (also cf. [4]).

It is therefore necessary only to compare station pairs of the same sea-level, previously checking these for possible terrain features by contrasting the extreme temperatures of several neighboring weather stations. Only a few mountain situations meet this criterion.

2. Differences of the Extremes in the Course of the Year.

From the weather network of the Bureau for Meteorology and Hydrology of Weimar, in the region of the Thuringian mountains (which shall include the Thuringian Forest and its southeast projection, the Thuringian schist mountains as well as the "Frankenwald") the pair of stations Sonneberg-Neufang (636) at the windward and Lehesten (640 m) in the lee, at medium and high situations, are suitable (Table 1).

The comparison of these 10-year climate means in no way reveals any distinct tendency. It is thus better to characterize the daily differences of the lee minus the windward side for the daily maxima and minima by means of frequency distributions. In order to disclose possible fair weather effects, an immediate

Table 1. Daily Mean Temperatures as Well as Mean Maxima and Minima of Sonneberg-Neufang and Lehesten 1947/56

	Daily Mean Temp.			Daily Mean Max.			Daily Mean Min.		
	Sonneberg	Lehesten	Dif.	Sonneberg	Lehesten	Differenz	Sonneberg	Lehesten	Dif.
Year	6,1	6,2	−0,2	10,0	10,3	+0,3	3,2	2,5	−0,7
January	−3,2	−3,1	+0,1	−0,9	−0,7	+0,2	−5,2	−5,8	−0,6
July	15,6	15,2	−0,4	20,3	20,3	0,0	11,6	10,5	−1,1

distinction was made between the fair and all other days (Fig. 1). It can be clearly seen that the differences of the daily minima of Lehesten minus Sonneberg are always negative, especially on fair days (top right). This signifies that Lehesten at the Frankenwald margin of the highlands is fundamentally too cold at all times of the year, in consequence of the nocturnal formation of cold air, and therefore is excluded with respect to the minima for comparison purposes. But the daily maxima are free of local effects (Sonneberg both day and night is free from local weather formations which, again by comparison with Brotterode and Schmiedefeld, R. a. a. O., has been established). While on the annual mean the frequencies of positive and negative differences between the daily maxima on fair and on all other days are balanced out (Fig. 1, left), in the annual course of the latter there is a distinct pattern: in January 47.3% of all days at Lehesten have a higher maximum than Sonneberg, but 20.7% have a lower, and on 32% of all days these places differ by only <0.3°C. However in July Lehesten is colder than Sonneberg on 35% of the days. Thus it is seen that a first indication of the annual course of the foehn effect is immediately revealed from the daily maximum temperatures.

Sonneberg and Lehesten lie at a distance of 25 km on the same streamline for both S or SW winds, and between these there is also a range which is hardly impressive. Therefore, in 1949/52 at Burkersdorf (615 m) above Schwarzburg a parallel station was maintained, situated exactly 30 km northeast of the free upland

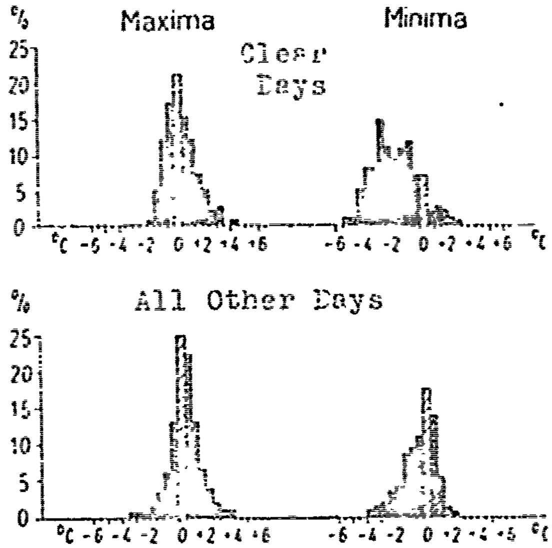

Fig. 1. Frequency distribution of the differences of the daily maxima (left) and minima (right) of Sonneberg-N. (636) minus Lehesten (640 m) 1947/56, top for fair and bottom for all other days.

station of Sonneberg and near the center of the large negative precipitation anomaly of the leeward side of the schist mountains. From pedological research by H. E. Jacob, graduate student in forestry at Jena, observations of extreme temperatures at Burkersdorf (640) have cordially been made available for the summer months of 1956/58 [5], so that three annual courses for the winter months, five for the spring and summer, and six for the autumn are available for the station pair of Sonneberg-Burkersdorf in order to form the differences.

For all 12 months of the year, the differences of the extreme temperatures in the frequency diagrams are shown by Fig. 2. It is to be noted that, when the class size is 0.5°, differences of -0.26 to +0.24° are coordinated with the class mean of 0.0° etc. The numbers to the left and right of the distribution diagrams signify percentage below and above this class mean. The differences between the daily minima, free of

l...al station effects, allow a distinct difference to appear between the winter and summer.

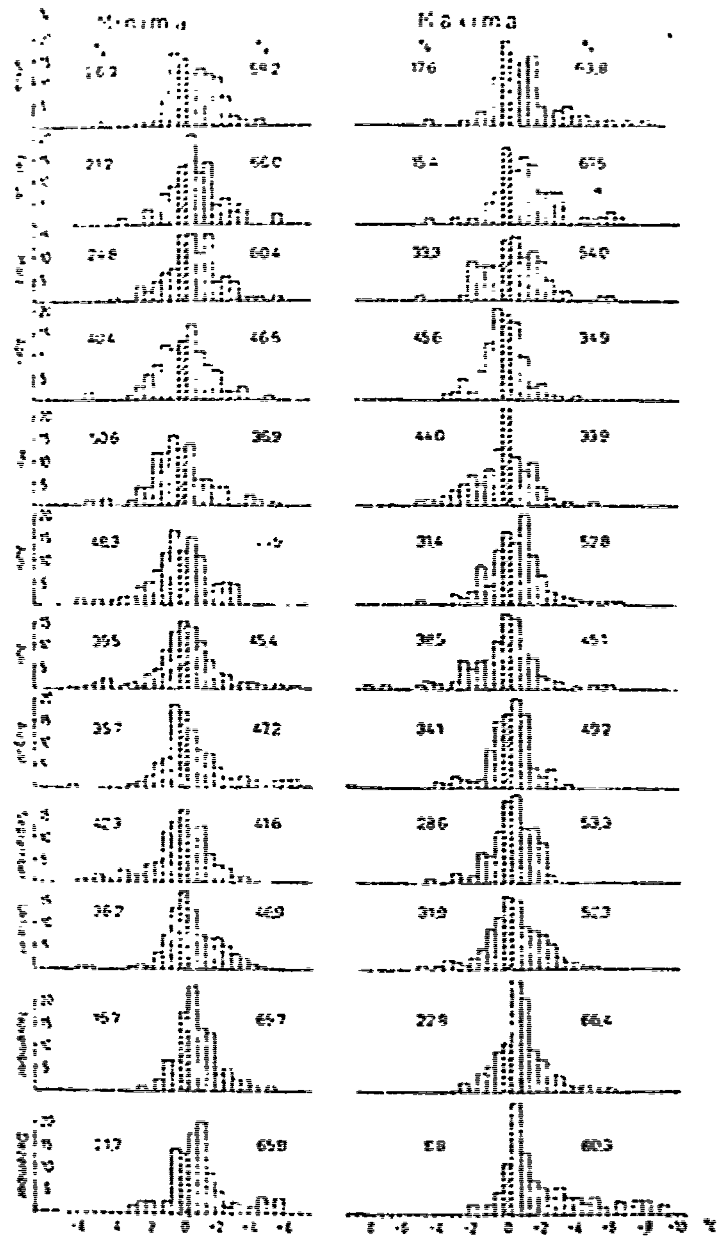

Fig. 2. Differences of the daily minima and maxima of Burkersdorf (640) minus Sonneberg-N. (636 m) for 12 months of the years 1949/52 and 1956/58. The numbers next to the frequency diagrams indicate percentage >±0.25° (positive = Burkersdorf is warmer).

Even more impressive, however, is the influence of the foehn weather situation (right column of Fig. 2), which distinctly obeys an annual course in the case of the maxima: from November to February the SW and W weather situations and thus the "foehn" situations prevail during these usually mild winters. In December the maximum is higher in Burkersdorf than in Sonneberg on 80% of all days! The spring months of April and May are often subject to NE winds - corresponding to the annual rhythm of the wind vector - so that Burkersdorf is warmer on only 35 to 34% of all days; the "northern foehn" is then manifested, Sonneberg being warmer on almost half of all days. With the cool summer weather, the SW winds and therefore the foehn situations again become frequent; from June to October Burkersdorf is warmer on approximately 50% of the days.

While Fig. 2 corresponds basically to the long-term average relationship, it is still greatly influenced by the individual nature of these few years. In any case, the familiar average annual course of the wind direction frequency, with peaks of the SW situations in the winter and at the height of summer, is distinctly reflected.

In contrast with the previously conventional techniques of characterizing the foehn weather situations by means of certain temperature and humidity thresholds - such as the height of the vertical gradient or the difference between peak and valley - in the following we shall thoroughly investigate all SW wind days as to whether there is any temperature difference between the windward and leeward, and whether in contrast an increase in heat at the southern flank of the mountains can be established on N and NE wind days. The results of a frequency sorting of the years 1949/52, carried out with this plan, are shown in Fig. 3. In the upper row (summer and winter) in comparing the daily means, the daily minima, and (especially convincing) the daily maxima, the excess heat of the lee station Burkersdorf on

SW wind days is fully disclosed. All six distribution curves show a preponderance of the positive differences. These are generally larger in winter than in summer. In the cold time of the year, Burkersdorf is warmer than Sonneberg on 86% of all SW wind days, usually by 0.3 to 1.8°; but there are also individual instances of a difference up to +4°. In the summer, 76% of the days in Burkersdorf are warmer, but only by 0.3 to 1.2°; larger differences are more seldom than in the winter.

As a confirmation, the lower row of this figure shows a preponderance of negative differences under NE winds, although these are lower than on the SW wind days. Even so, the variation of the differences is smaller, and as a consequence of the lesser number of cases the distribution curve is less smooth. But still in the winter Burkersdorf is warmer on NE wind days in only 29% of the cases, or 10% in the Summer, while in 44 and 65% of the cases, respectively, it is colder than Sonneberg (rounded-off data in Fig. 3).

Hence, the existence of both a southwest and a northeast foehn should be regarded as proved.

3. Leeward/Windward Differences in the Daily Temperature Course

A much better possibility for appraising the thermal foehn effects than the daily means and extremes are current temperature (and humidity) registrations at leeward and windward stations of identical altitude. These were available for the summer months of July through October and June through August 1957 by a special network, set up on both sides of the schist mountains for forestry climatic purposes (for more details, cf. [8]).

In the Schlagetal near Meura/Kreis Neuhaus/R., 10 km north of the Rennsteig, an opportunity was found to set up leeward stations in an exact west-east direction of a segment of the

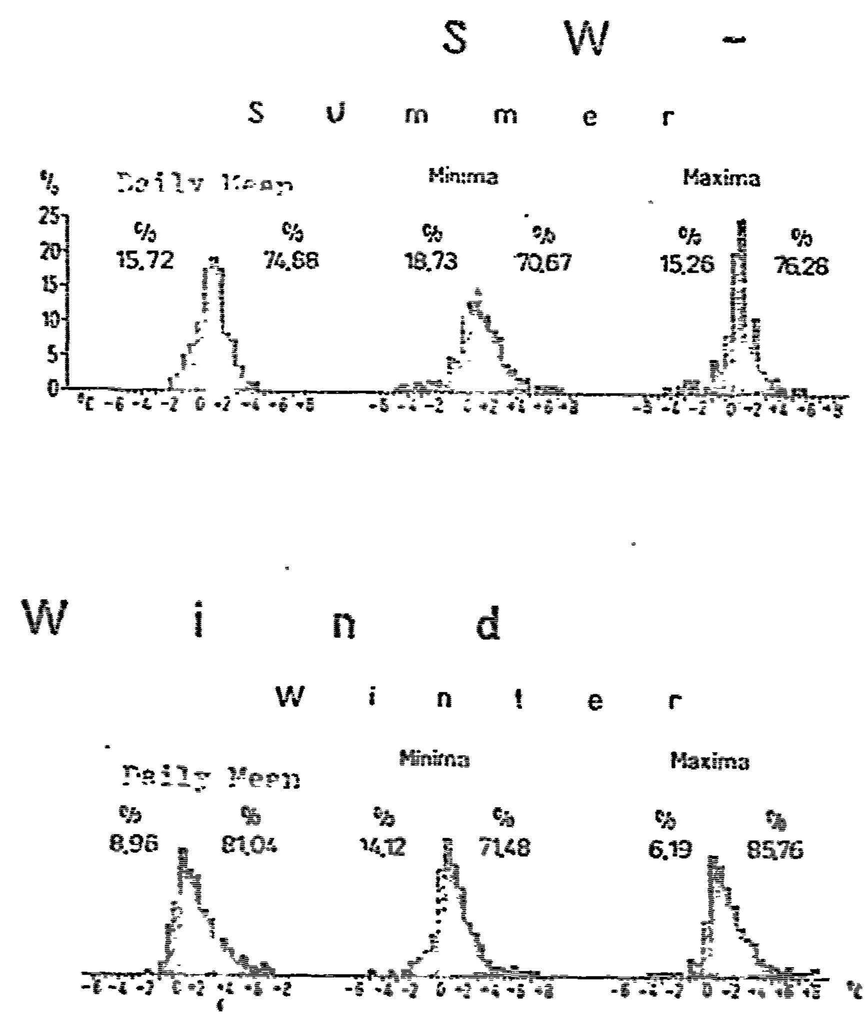
SW - Wind
Summer
Daily Mean
Minima
Maxima
%
25
20
15
10
5
0
%
15.72
%
74.88
%
18.73
%
70.67
%
15.26
%
76.28
Winter
Daily Mean
Minima
Maxima
%
8.96
%
81.04
%
14.12
%
71.48
%
6.19
%
85.76
°C

Fig. 3.

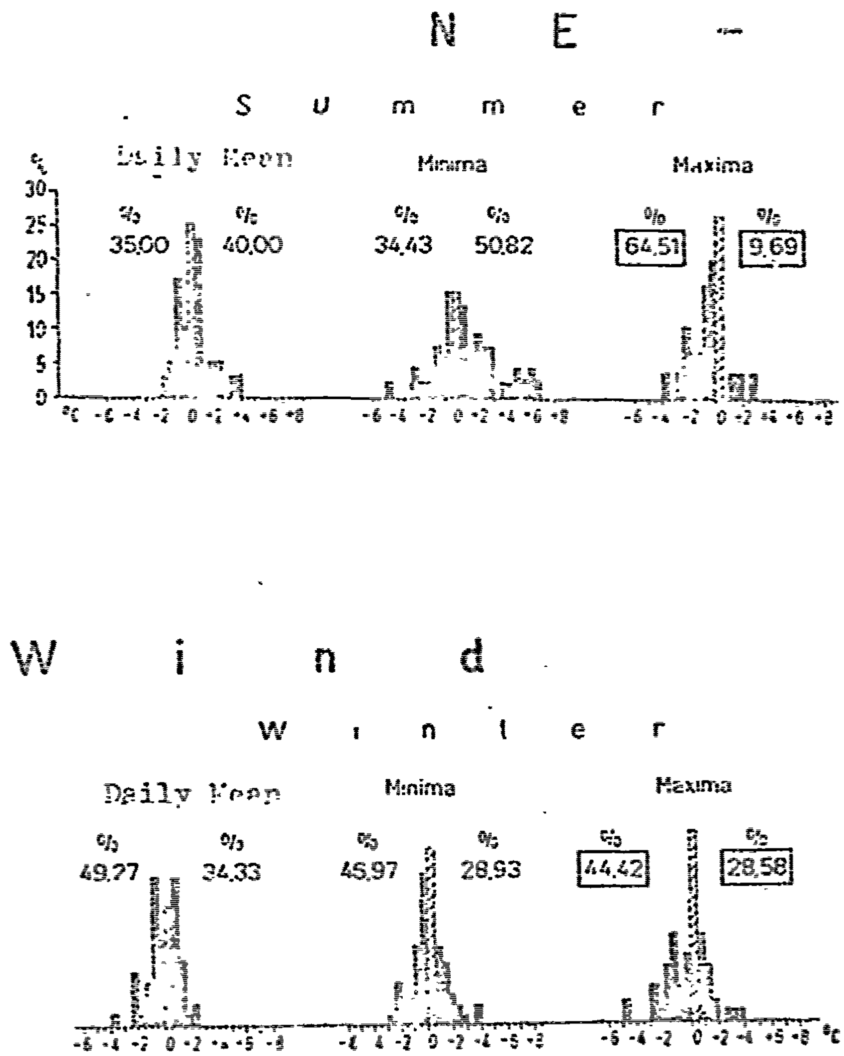

Fig. 3 Continued. Differences of Burkersdorf minus Sonneberg-N. 1949/52 for the daily means of the temperature (left), daily minima (middle) and maxima (right), divided into winter and summer for all days with SW (top) and NE (bottom) wind. Numbers near the frequency diagrams indicate percentage >±0.25° (positive = Burkersdorf is warmer).

steep and narrow Kerbtal, and windward stations in the parallel Steinbachtal, a steep, incised side valley of the Neumannsgrunde, 5 km south of the Rennsteig. The "valley stations" both lay at 500 m above NN., the two "north slope" and the two "south slope stations" at 660 m, the peak station of Meura at 706, and the other peak station at 764 m sea-level in an angle between Neumannsgrunde and Steinbachtal. In addition to the measurement sites at the slope of the V-shaped valley, all the stations were erected in the original range of rather old spruce trees without a shrub cover, at identical height and with identical degree of enclosure, so that the measurements are definitely comparable. For the present purposes, both of the valley stations, as well as the two north slope stations were chosen for the evaluation, the latter primarily because any incr[illegible] in the daily temperature at the southern slopes by direct sunlight had been excluded.

The deviations of the temperature curves of the valley and slope stations provide an idea as to how greatly and variably the "fair weather effects" influence the daily course. When the sky was overcast all day, the slope stations could not fail to assume a lower and parallel course both day and night, corresponding to the altitude difference of 160 m. Depending on the degree of cover and the cloud density, however, the valley becomes colder at night and warmer throughout the day, than the slope (much less the summit) with its equalized amplitudes, by an amount which is in fact the larger the more the periodic daily sunlight effects are able to manifest themselves. In the summer - more or less - this is always the case. The question as to a leeward heating by the effects of the foehn, can only be answered under consideration of this fair weather influence, since there are considerable differences between both halves of the mountain chain, even on fair days with little wind. A heating of the lee side by the foehn will only be real, therefore, if the above influence is distinctly superimposed or entirely overcompensated.

For this reason, in Fig. 4 the mean temperature course for 26 definitely fair and nonwindy days is shown. This is primarily characterized by a very large amplitude - especially for the valley stations. Furthermore, however, there are also differences between Schlagetal and Steinbachtal, which are orographically occasioned: the valley station in Schlagetal lies in a segment of the valley in which the steep slopes at both sides of the Bachbett somewhat recede and only reach to 170 m. For this reason, the solid angle of the unscreened portion of the sky and thus the effective radiation is stronger. In comparison, at the bottom of the valley of the narrow, 270 m deep, incised Steinbachtal with its narrow gorge at the windward side of the range it is several degrees warmer at night, but here throughout the day there is less sunlight, due to the greatly constricted horizon, and the overall valley cross section remains colder than in the case of Meura. Thus, at the valley and slope stations of Meura there is a heat excess in the day and a deficit at night.

The deviations of the hourly temperature difference leeward minus windward (Fig. 7a and b) have very large variations in individual cases on fair days (point cloud representation not shown). Thus, at sunrise, the values are between -5.0 and +2.5°, at midday between -4.5 and +6.5°, at evening between -5.0 and +4.5°, and at midnight still between -6.5 and +4.0°, an indication of the great fluctuations from day to day in the temperature field of the air layers near the ground.

The duration of sunshine, according to the data of the heliographs of Sonneberg-Stadtberg and Saalfeld-Feengrotten, is hardly reduced at all and exactly identical on the average; only early in the morning and in the evening does the outlet of the valley of Feengrotten experience much shadowing.

We must now verify whether on days with southwest winds,

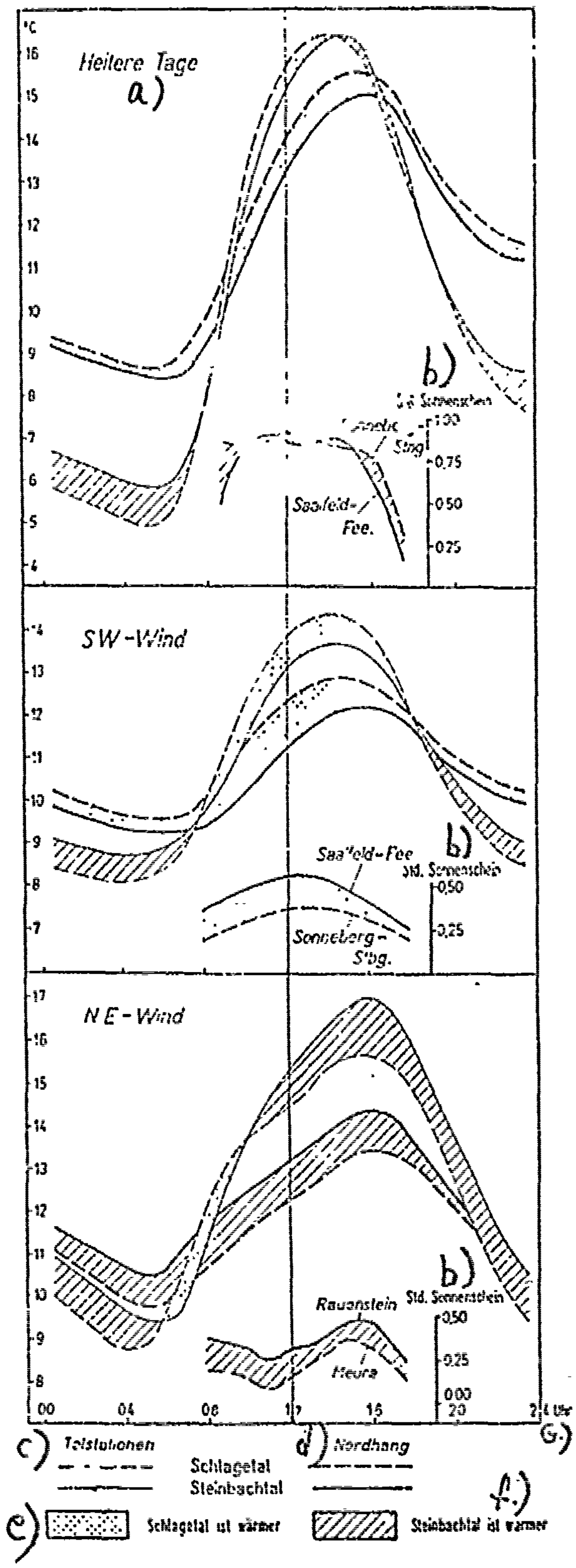

Fig. 4. Average daily course of the temperature and the duration of sunshine for the valley and slope stations in Schlagetal near Meura (North) and in Steinbachtal (South) in the summer months of

Fig. 4 Cont'd.
1956 and 1957. Top, 26 fair and low-wind days, middle 60 SW-wind days, bottom 18 NE-wind days. Key: a) fair days; b) hours of sunshine; c) valley stations; d) north slope; e) Schlagetal is warmer; f) Steinbachtal is warmer; g) hours.

of which in Fig. 4, middle, 60 items have been comprised in an average daily course without allowing for the weather situation, important foehn-occasioned temperature effects can be established as deviating from this fair weather picture. It is seen that the daily amplitudes of the valley and slope stations are contracted at the half, and also the temperature increase with height in both cross sections of the valley, as well as the windward/leeward differences at night, are greatly reduced, an indication of a significant, but not yet total elimination of the fair weather effects by clouds and wind. But in the day the difference of the lee minus the windward side at both stations is greatly increased, so that the anticipated heat increase at the lee side is in fact fully manifested.

In connection with this obvious effect of the foehn, the evaluation of the sunshine autographs reveals that, on these 60 SW-wind days, Saalfeld receives constantly more direct sunlight, and in fact reaches the hourly excess at noon in an average of 1/4 hour! In order to better depict this phenomenon, significant for the heating of the lee side, let us further present a frequency sorting of the half-day differences in sunshine at both sides of the mountain (Table 2):

Table 2. Frequencies of the Half-Day Differences of Duration of Sunshine Saalfeld-F. Minus Sonneberg-St. in Percentage on 60 Days with SW-Winds.

Size of Difference in Degrees	positive					negative			
	5–4	4–3	3–2	2–1	1–0	0–1	1–2	2–3	3–4
Forenoon	3,5	3,5	10,3	18,9	39,6	13,8	8,6	0	1,7
Afternoon	1,8	3,6	3,6	21,8	38,2	23,6	5,5	1,8	0

Although Sonneberg-St. with 636 m represents a mountainous situation at the southern marginal fault of the schist mountains, the data is still significant for the shadow-covered foothills. Since here more than 1/3 of all SW-wind days in Sonneberg for half the day have only 0 to 1 hour less sunshine, and 1/5 of the days 1 to 2 hours less, than Saalfeld, can be attributed to the fac~ that many fair days have been included, on which there were little or no condensations of clouds at the windward side, when the level of condensation lies far beyond the height of the summit. The significance of the sunlight differences for the heat available to both halves of the mountain chain is nonetheless distinctly revealed.

As a control test for the heat excess of the north side, Fig. 4 shows the daily course of the temperature and the duration of sunshine on all available days with northeast wind. Here the fair weather effect is even more manifested, as the proportion of fair days is larger, by the fact that the daily amplitude is larger than that on days with SW wind. But the temperature difference North minus South at night has become negative only at the slopes, but in the days at the slopes and in the valley; i.e. Steinbachtal, which now lies in the lee, is warmer across the entire section of the valley than the Meura stations to the north of the ridge! Also with respect to the duration of sunshine the southern side - repre~~ated here by the "open country station" of Rauenstein (555 m) - is definitely preferred over the similar stations at Meura (560). Thus, similar to the above, it is again demonstrated for the station pair of Sonneberg-Burkersdorf that, depending on the prevalence of the northern or southern component of the wind, the southern or northern half of the mountain chain experiences a foehn heating and retreat of the clouds.

In order to consolidate these findings, Fig. 5 shows the hourly temperature differences of Meura minus Steinbachtal in a

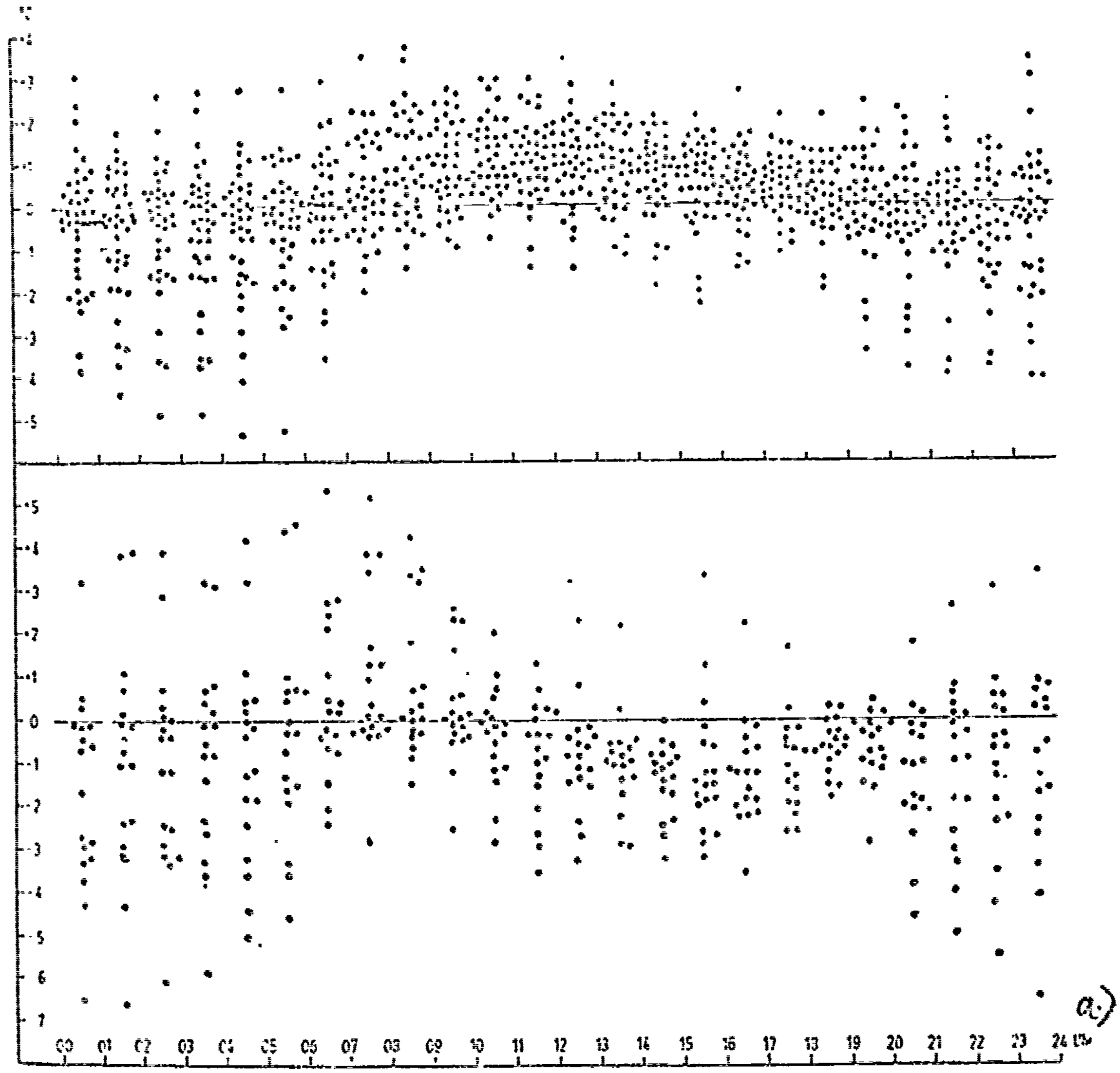

Fig. 5. Daily course of the individual values of the temperature differences of the valley station Schlagetal (lee) minus the valley station of Steinbachtal (windward), top, on 40 days with southwest wind, bottom, on 18 days with northeast wind. Key: a) hours.

point cloud diagram as well. The SW wind days (top) deviate from the NE-wind days, on the one hand, by the fact that, on the former, the majority of points lie above the zero line, with

the exception of the early forenoon, when a fair weather effect sets in, and then they lie below the zero line; on the other hand, they differ in their amplitude of variation. The SW-wind days generally reveal a very tight bunching on an amplitude of not much more than 3°. Before noon, the differences vary only between -1.5 and +3°, in the evening between -2 and +2°. But in the hours of the night, the amplitude of variation again assumes isolated high points, while in the valleys with cloud dissipation and increasing wind deficit the valley inversions return, as could be noted in Fig. 4, middle.

The pair of slope stations reveals a much smaller amplitude of variation of the individual values, as shown by a comparison of the point clouds of Fig. 5 below with those of Fig. 6 top, although these concern the same selected NE-wind days. It follows at once that, on account of the decrease in the daily amplitude of fair weather days and other local phenomena, slope stations with a maximum angle of inclination are much superior for demonstrating foehn effects than valley stations.

Since the Thuringian Mountains basically stretch from SE to NW, the orographically occasioned temperature differences of both sides of the range in the event of SW and NE winds must naturally be the largest, and the smallest in the case of NW (and the more seldom SE) winds. This is shown by the lower point cloud diagram in Fig. 6, which differs only slightly from that of the fair days (not shown). The experience that there are no foehn phenomena at the Thuringian Mountains under NW winds can be demonstrated, e.g., from the daily charts of the precipitation distribution. A "northwest calm back-up" or a windward intensification in the precipitation in the northern foothills of the western Thuringian Forest takes place under neither NW or N winds. In the majority of post-cold frontal weather conditions, the wind above 1000 m usually arrives anyway

from the W or SW; the normal or an irregular precipitation distribution pattern therefore sets in. Under the large autumn and winter slip fronts, and therefore also on the yearly average, the rain maximum on account of the smallness of the mountains in this part tips over to the lee side, which is perfectly regular, but in no case is it north of the mountain border.

The previous results can be summarized once again in Fig. 7, where the daily course of the mean hourly temperature difference leeward minus windward in the three different main wind directions for the pair of valley stations can be compared with that on fair days. In this regard, NW-wind days deviate only slightly, but SW-wind days substantially and cloud-rich NE-wind days fundamentally, from the above.

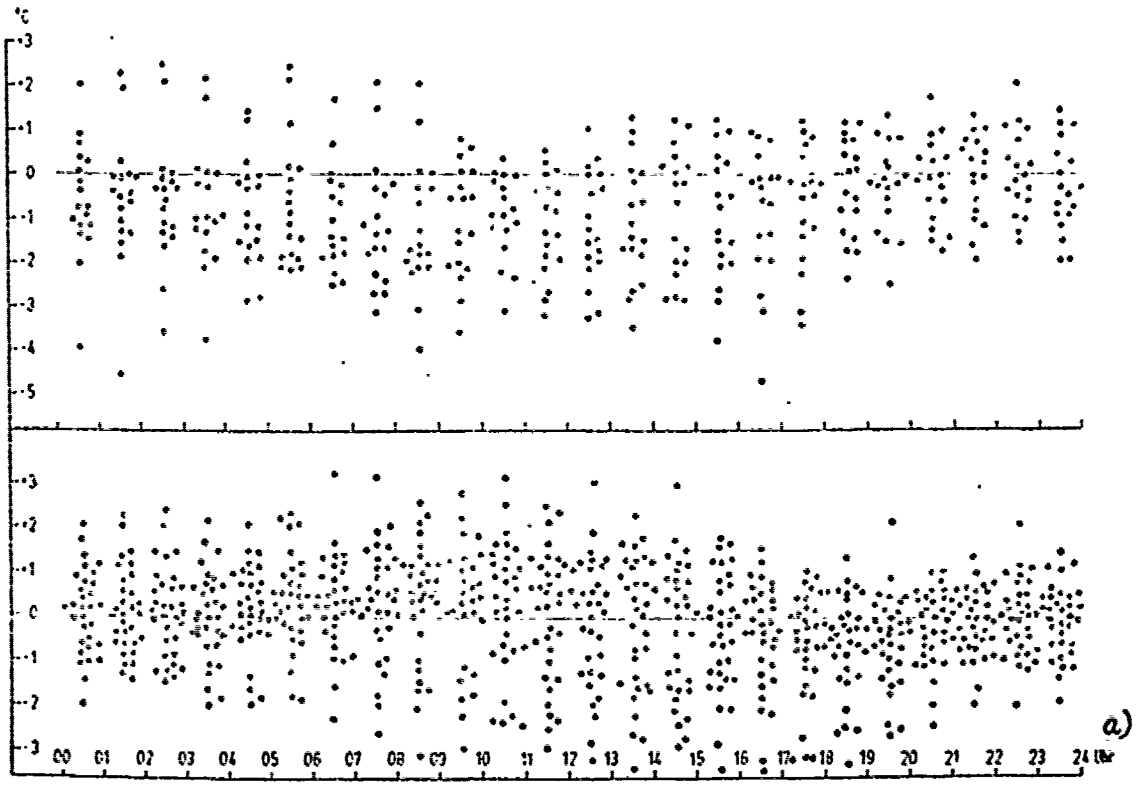

Fig. 6. Daily variation of the individual temperature difference values of North slope station Schlagetal (N.) minus N. slope sta. Steinbachtal (S.) on days of NE wind, top, and on 33 days of NW wind, bottom.

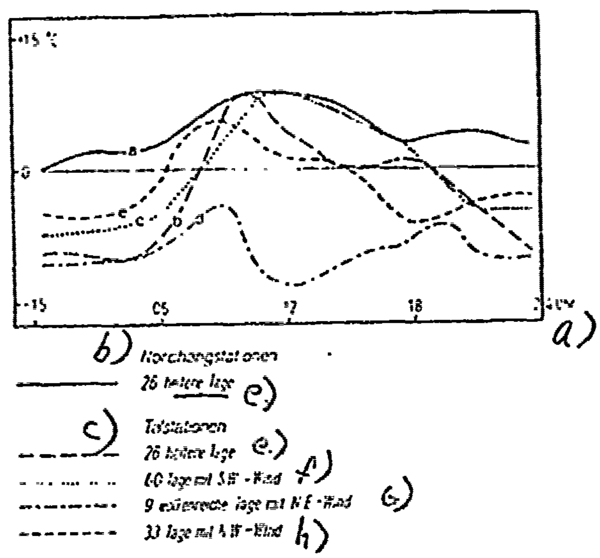

Fig. 7. Average hourly values of the temperature differences of both northern slope or valley stations (Schlagetal minus Steinbachtal) on fair days, as well as days with SW and NE winds. Key: a) hours; b) north slope stations; c) valley stations; e) fair days; f) days with SW wind; g) cloud-rich days with NE-wind; h) days with NW wind.

4. Selected Situations of the Central Mountain Foehn

4.1. Warm Fronts with Southwest Wind

Now that we have generally demonstrated an orographically-occasioned temperature effect when the wind is not parallel to the mountain range, we must specially select all those situations of SW and NE-wind at which the increase in heat at the lee side is particularly high. At first we shall present all the available warm fronts with SW wind from the summer months of 1956 and 1957, as these allow the most intense dynamic heating of the lee side.

The mean daily course of 20 first and 15 second halves of the day can be seen in Fig. 8 at the top. A sorting was

necessary, since in the case of summer warm fronts the cyclonal foehn stage endures all day long only in a few instances, and the beginning or end usually fall on the intermediate hours. However, the "interrupted" half-days for those hours on which the foehn had not yet begun or already concluded were given a complete allowance. Otherwise temperature jumps would also occur in the half-day curves, such as are unavoidable at noon and midnight, given the different number of days.

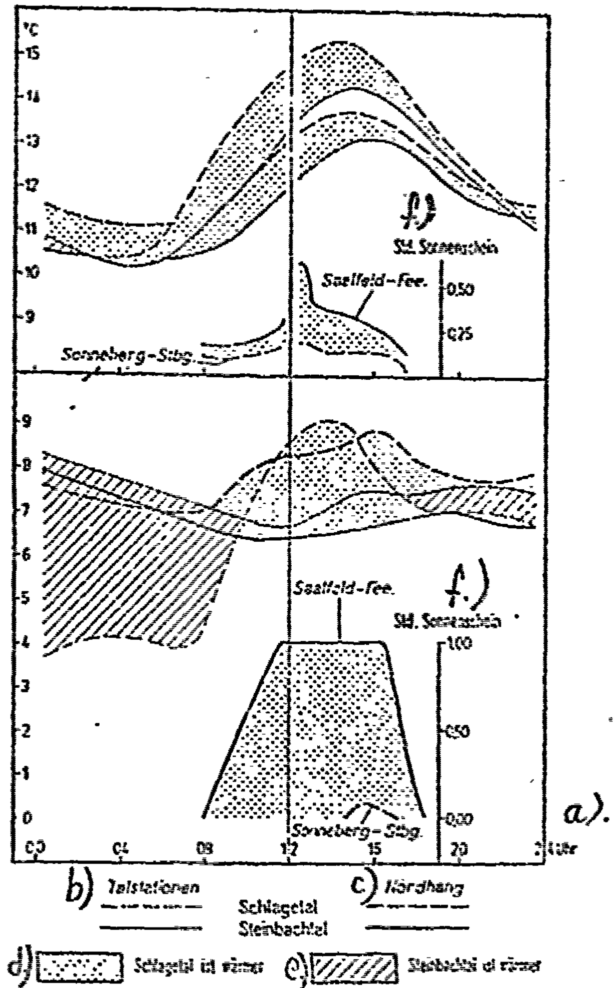

Fig. 8. Mean daily course of the temperature and duration of sunshine for the valley and slope stations in Schlagetal at Meura (lee) and in Steinbachtal at Neumannsgrunde (windward) in the summer months of 1956 and 1957. Top, for 20 forenoon and 15 afternoon days with warm fronts under SW wind, bottom for

Fig. 8 Cont'd.
2 days with fog congestion at the southern margin in October 1956. Key: a) hours; b) valley stations; c) northern slope; d) Schlagetal is warmer; e) Steinbachtal is warmer; f) hours of sunshine.

Although the choice of the warm front situations was made only with respect to the weather conditions and not the height of the condensation level, the leeward warming is present all day long to a high degree. Especially noteworthy are the forenoon heat excess of the valley stations at Meura, which greatly exceeds the difference of the fair days, as well as the night and forenoon heat increase of the leeward slope stations. Even the otherwise-effective radiation effect, which persistently keeps the Schlagetal colder than the narrow Steinbachtal at night, is completely compensated by the foehn influence from 00 to 02 hours! The amount of sunshine at the lee station of Saalfeld was found to be particularly effective at midday. The difference in the daily course of the temperature differences between the valley and the slope can be seen from Figs. 9a and 10a (cf. in particular the high all-day curve of Fig. 10a for the slope station!).

4.2. Cloudy SW-Wind Days

The sought foehn effects appear even more clearly by plotting a mean temperature course with especially cloudy or continuously rainy SW-wind days, as can be seen in Fig. 11. These represent the weather conditions with low condensation level, when not only the windward side is shrouded in the low-lying clouds (Sonneberg station is usually in fog), but also the north side remains thoroughly overcast, so that there can be no heating in this case by direct sunlight. During these 13 half-days, the heliograph of Feengrotten registered a total of 0.4, that of Stadtberg 0.6 hours, so that the thermal differences can in no way be interpreted as effects of radiation or local

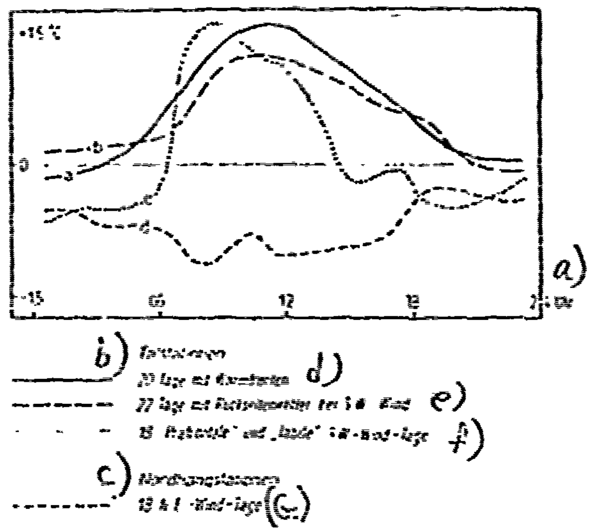

Fig. 9. Mean hourly values of the temperature difference of both valley or north slope stations (Schlagetal minus Steinbachtal) on days with four different weather conditions. Key: a) hours; b) valley stations; c) north slope stations; d) days with warm fronts; e) days with post-cold frontal weather and SW wind; f) pre-frontal and "labile" SW-wind days; g) NE-wind days.

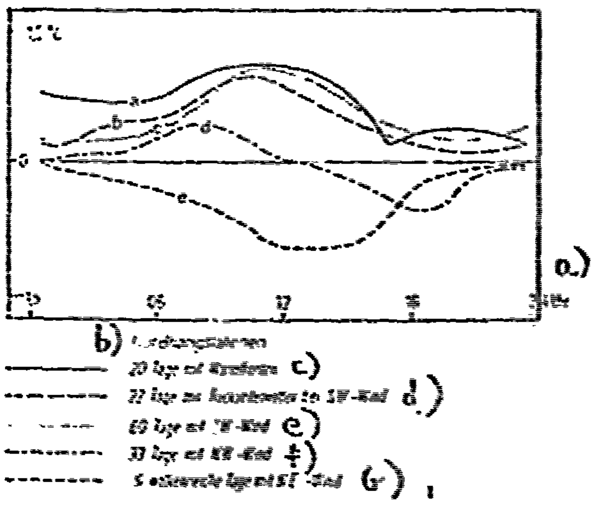

Fig. 10. Mean hourly values of the temperature difference of both north slope stations (Schlagetal minus Steinbachtal) on days with five different weather conditions. Key: a) hours; b) north slope stations; c) days with warm fronts; d) days

Fig. 10 Cont'd.
with post-cold frontal weather and SW wind;
e) days with SW wind; f) days with NW wind;
g) cloudy days with NE wind.

climate. The daily amplitude consequently amounts to only 3.5° in the valley, and only 1.5° on the slope! Between the windward and leeward sides on the slope there are mean differences of 0.4 to 0.8° generally, while in the valleys at night they are 0.4, at midday up to 1.2°. The vertical temperature gradient per 100 m extends to 0.35 in Steinbachtal, 0.6 in the Meura valley, but at midday the latter may be 0.35 or 1.0°. While the overall thermodynamic foehn process of rising and sinking may not conform perfectly to an ideal foehn process, the ascertained values must nonetheless be regarded as genuinely real, and the foehn heating at the leeward side under a low condensation level and closed cloud cover must be regarded as "genuine".

4.3. Pre-Frontal SW-Wind Days

In sharp contrast with these overcast SW-wind days are the "pre-frontal" and the "labile" SW-wind days, which even under a medium-high cloud level disclose the typical foehn sky with numerous lenticular ice forms and a general tropospherical warming with at times very intense global radiation; however there is neither an orographic cloud build-up to the windward (foehn wall) nor a leeward cloud dissipation, but rather both windward and leeward experience the foehn warmth at the same time and display the same foehn sky, and even in lowlands away from the mountains, such as Northern Germany, a "foehn" prevails, judging by the cloud pattern, and even meteorotropic foehn problems can be observed in rather large numbers under vegetative instabilities. This concerns almost exclusively the large tropical air impacts against the front of the East-Atlantic Depressions, when the condensation level is above 2500 m. As important as these primarily summertime situations may be in

regard to bioclimatology, their meteorological and biological effects must nonetheless be ascribed solely to the pre-frontal synoptic condition, and in no way to an orographic foehn effect.

In this group of "pre-frontal" SW-wind days are included certain "unstable" conditions, during which certain pre-frontal heat waves within the maritime tropical air occasion a tendency to storms and more intense cumulus formations over all of Central Germany, without the terrain influences having an effect at the mountain range. The daily course of the temperature difference of leeward minus windward consequently resembles that of the fair days to a great extent, only the night differences being equalized and possibly the windward sides receiving slightly less sunshire (cf. Fig. 9c).

An additional foehn-like situation, which greatly favors a thermal preferment of the lee in the climatological mean by exceptional isolated cases, is the formation of lowland fog in the southern foreland and its burn-off up to the mountain crest. This fog still belongs to the anticyclonal foehn stage. Unless it concerns a vertically extensive radiating fog, it is to be understood that the fog is a low, enclosed cover of stratus clouds, created by the forced lifting of the bottom layer of air within the foundation layer as a consequence of flowing against the lower foothills, while the mountains and the northern foreland have no clouds at all in a fair sky. Under a stronger Southwest wind and forenoon thermal conditions, the cold air rises to the height of the crest, shrouds the mountains of the windward side up to 600 or 800 m, and interrupts the anticyclonal foehn stage for hours with strong temperature recession and increase in humidity, until it withdraws, usually by evening, to the southern foreland or, in the event of a high or medium-high gathering of clouds, passes into the stationary foehn stage. The summits and the lee side are usually spared, and normally the fog quickly dissipates at the lee side after moving

beyond the clefts of the mountain passes. An enclosed, low foehn wall stretches from the North, above which there is blue sky.[1] It is clear that in this case the stations of the lee will register the extreme annual course of the fair days and full sunshine, while the windward stations will register an equalized temperature course and no Sun at all, as shown in Fig. 8 for the example of two days. In autumn and mild winters, these situations are especially frequent.

4.4. Post-Cold Front Weather With SW-Wind

The group of foehn weather conditions which is of greatest interest and comprises the most numerous contingent of all foehn situations, is surprisingly post-cold frontal weather with southwest advance of air. In both summers 1956 and 1957, for which we have available a total of 7 months with thermograph recordings, there were:

130 half-days with SW-wind, of which there were

21 half-days with "pre-frontal" or "unstable" SW-wind conditions,

41 half-days with warm fronts and SW-winds,

67 half-days with cold fronts and post-cold front conditions with SW-wind, in addition to

52 half-days with NW-winds and

30 half-days with N and NE winds.

Several of these have been counted twice when they concerned two different weather situations. The selection of the wind directions was made by climate observations four times a day of the larger Inselsberg, 60 km away. Since the number of hours with warm fronts is much smaller than that of post-cold front weather, due to the rapid front passages, the latter conditions decisively control the weather manifestations, especially during

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[1] Portraits of two such cases are found in [6], p. 109/110.

the normally changeable months of mid-summer.

Fig. 11, middle, shows the mean daily course of the temperature and duration of sunshine of the valley and slope stations at leeward and windward for 12 post-cold frontal weather half-days. Only those days were chosen which revealed rather large differences of sunshine duration at both sides. This reveals, in contrast with the curves in Fig. 4, middle, for all SW-wind post-cold frontal days, the foehn effects in full clarity:

1. The leeward stations are warmer, not only at the slope, but also in the valley; the fair weather influence at night is fully compensated by the foehn effect.

2. The slope station, and particularly the valley station of the lee is up to 1.7° warmer on the average than the corresponding windward station, in many isolated cases the hourly value of the temperature difference during the day rising by more than 2.5°; while the windward side is usually in shadow, the leeward station has much more Sun and heats up in almost the same fashion as on fair days; the fair weather and pure foehn effects complement each other and result in an overheating of the lee side, which is therefore always the greatest between the hours of 08 and 17.

3. The differences in the amount of clouds are the greatest of all the previously adduced instances; while the Feengrotten receive about 60 to 70% of the possible sunshine, the Sun at Sonneberg appears for only 20 to 40% of the time. In a remarkable manner, in Fig. 11, middle, from 16 hours on the sunshine and, equally, the temperature curves of the windward and leeward stations draw together, as suddenly there is more sunshine at Sonneberg; thus, between 16 and 17 hours, the windward stations as well - in comparison with the lee stations and their delay of up to 3 hours - attain an additional distinct daily temperature maximum.

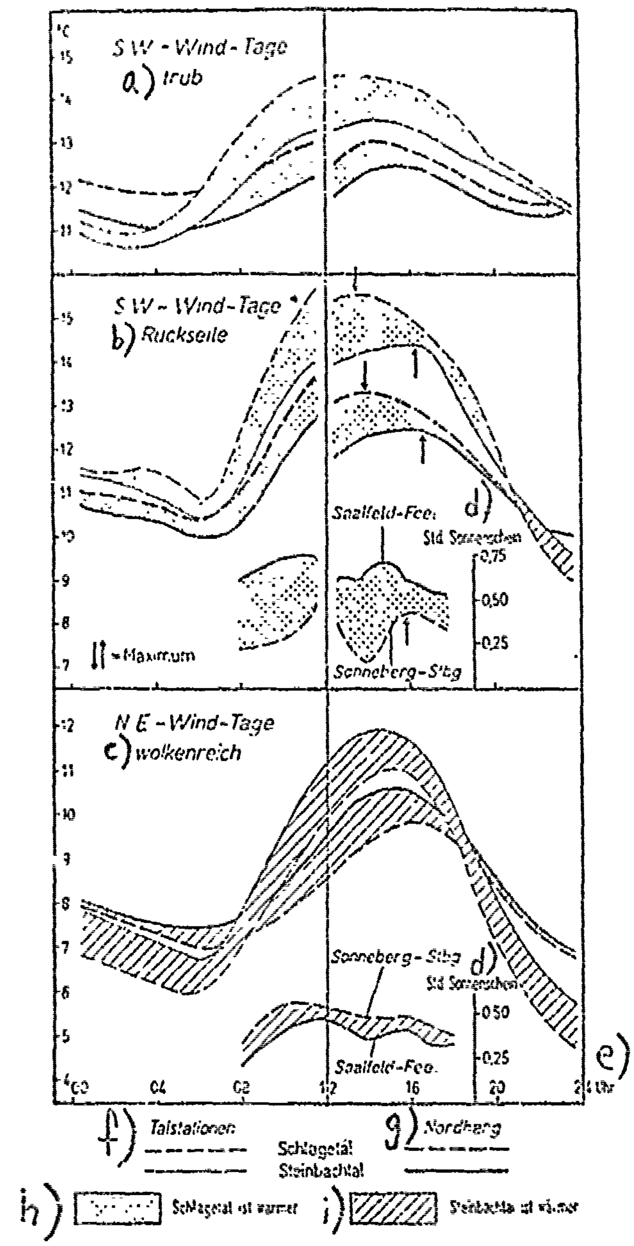

Fig. 11. Typical situations in the Central Mountain foehn. Mean daily course of the temperature and the sunshine duration for the valley and slope stations in the Schlagetal at Meura (North) and in the Steinbachtal (South) in the summer months of 1956 and 1957. Top, for 13 cloudy, rainy, SW-wind half-days; middle, for 12 SW-wind half-days with post-cold front weather and large cloud differences; bottom,

Fig. 11 Cont'd.
for 9 cloudy NE-wind days, at times Vb-days.
Key: a) overcast; b) post-cold front weather; c) cloudy; d) hours of sunshine; e) hours; f) valley stations; g) north slope; h) Schlagetal is warmer; i) Steinbachtal is warmer.

The close connection between the cloud processes and that of the temperature difference also follows from the hourly values of 21/7/1957, one such SW-wind post-cold front weather day:

Table 3. Hourly Values of the Duration of Sunlight of Saalfeld-F. and Sonneberg-St. as Well as the Hourly Temperature Difference of Schlagetal Minus Steinbachtal, Valley and Slope, on 21/7/1957, 12-19 Hours.

Clock Time	12–13	13–14	14–15	15–16	16–17	17–18	18–19
Saalfeld-Feengrotten	0,8	0,8	1,0	0,8	1,0	1,0	0,6
Sonneberg-Stadtberg	0,9	0,2	0,2	0,8	0,7	0,7	0,1
valley stations	+2,7	+2,5	+1,9	+1,2	+0,3	+0,5	+1,3
north slope sta.	+2,9	+2,8	+2,4	+2,2	+1,9	+1,8	+1,2

Just as, on the lee side during the day the full sunlight results in an overheating, at night a free and, due to the dry air, rather intensive emanation of heat during this post-cold front may stimulate the formation of a thin layer of cold air near the ground, over which the foehn air glides. At times the latter may penetrate to the ground and temporarily interrupt the nightly temperature drop. At rather large mountain heights, these "paradoxical" foehn effects are especially frequent.[1]

4.5. Cloudy NE-Wind Days

In conclusion let us note the NE-wind situations, of which in Fig. 11, bottom, 9 most cloudy days with leeward warming have

[1] One such case, when Friedrichroda experienced a complete foehn, while Bad Koesen under a clear night only received a foehn impact, is depicted in note [6], p. 104.

been chosen, 4 of which belong to Vb-weather situations. This pattern differs from that of Fig. 4, below, for all 18 NE-wind days as a consequence of the exclusion of the fair days, specifically:

1. by the lowering of the daily amplitude,

2. by the drawing together of the valley and slope stations, and

3. by the persistent all-day excess heat of the leeward (southern) slope and primarily the leeward valley stations. The excess heat, again, can be ascribed in part to the foehn sinking in the lee, but mainly the dissipation of the clouds at the southern side. As an example, we mention 2/8/1957. From 14 hours, with full sunshine at windward as well, the differences immediately recede from 2 to 3° to the customary 1.5 to 0° of fair days. Also the fact that, in accordance with Fig. 4, below, the largest windward/leeward differences on the average of all cloudy NE-wind days occur between 11 and 16 hours, indicates the paramount influence of the sunshine (at night under clear sky the Meura valley is always colder than the Steinbach valley, anyway).

Table 4. Hourly Values of the Duration of Sunshine of Saalfeld-F. and Sonneberg-St. as Well as Meura and Rauenstein (Top), in Addition to the Hourly Temperature Differences of Schlagetal Minus Steinbachtal (Bottom) on 2/8/1957.

Clock Time	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18
Saalfeld-F.	—	—	—	—	—	—	0,5	1,0	0,9	0,9	0,8	0,2
Sonneberg-St.	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	0,9	1,0
Meura-Freiland	—	—	—	—	—	—	0,3	0,5	0,9	1,0	1,0	1,0
Rauenstein-Freiland	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
valley sta.	−2,4	−2,8	−1,5	−2,5	−3,8	−3,5	−2,4	−1,4	−0,8	−0,6	−1,1	−1,6
north slope st	−1,9	−1,7	−2,0	−2,1	−2,3	−2,9	−1,7	−1,6	−1,2	−1,5	−0,1	+0,9

The fact that, on the other hand, the southern halves of the mountains are always slightly warmer, even on completely overcast days with NE-wind is shown by the following table, in which the three Vb-type days are combined into a mean daily course of the temperature differences:

Table 5. Mean Hourly Values of the Temperature Difference of Schlagetal Minus Steinbachtal on Three Cloudy Days with NE-Wind.

Clock Time	0–2	2–4	4–6	6–8	8–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24
valley sta.	–0,2	0,0	+0,1	0,0	–0,3	–0,6	–1,1	–1,1	–0,6	–0,4	–0,3	–0,1
north slope sta.	–0,5	–0,5	–0,5	–0,6	–0,6	–0,9	–1,1	–1,0	–0,9	–0,7	–0,7	–0,7

On these three days, the Sun appeared in Sonneberg for no more than 0.4, in Saalfeld 0.5, hours. Nonetheless, as a result of a slight nighttime cooling on 24/6/1957 in the Steinbachtal, a certain daily course can be noted for the valley stations, but not the stations of the northern slope, so that here the heat excess of the leeward southern halves of the mountains should be ascribed exclusively to the dynamic heating of the foehn process.

5. Foehn Phenomena and Cloud Formation

The previously cited cases clearly show that, despite the low height of the Thuringian Mountains (800-900 m), a leeward warming is always present, insofar as the wind strikes the mountains perpendicularly, and furthermore there is either a difference in the degree of cloud cover at both sides of the mountains, or a pressure buildup or dissipation in the event of overcast sky, at least in the lower and middle layers. Cloudless days, fair days with equal cloud cover at both sides, and "pre-frontal" days with high cloud cover or foehn forms indicate, at any rate, no orographically-occasioned foehn effects, even when wind is present.

Although in many cases the influence of the different radiation influx and efflux prevails, on the other hand even in the warm time of the year we may discover a modicum of foehn situations, when the radiation effect is entirely excluded and the particular warming and drying of the air must be ascribed to the thermodynamic foehn process alone. As examples of this we refer to the above practically sunless cloudy days of SW and NE wind, with a lower windward condensation limit below the mountain crest. All the phenomena in the thermograms and hygrograms, so characteristic for the mountains, such as the spikes at the beginning of the foehn warming process or especially the humidity drops at unusual times of the day, which so excellently characterize the foehn process, are utilized on a miniature scale, but with perfect clarity, in the recordings of the Central Mountain measurement stations (examples of this are not reproduced). The amount of leeward warming and drying is the larger as the temperature (and thus the absolute humidity) is higher and the condensation level lower. The former produces a larger amount of leeward warming for the summer, than the winter, so that for this reason the summer temperature effects are more striking; however in the cold half of the year the condensation level is more often below the mountain summits, so that the true foehn processes are more numerous than in the summer, even in consideration of the larger number of overcast days.

Overheating of the leeward slope stations by 1°, which according to Fig. 11, top, as well as Table 5, is to be regarded in general as an average working value, presupposes windward elevations up to 1000 or 1200 m, in the case of an ideal foehn process and a condensation level of 800 m above NN in the summer, or 1200 to 1400 m under mild winter situations. At excess temperatures of 2° for the medium height situations, which are more often detected in isolated cases under an overcast sky, we must assume elevations up to 1200 to 1400 m in the summer, or

1400 to 1700 m in the winter. Since the constrained rising is initiated in the foreground of the mountains and especially in the Eastern Thuringian Mountains there is a sufficient range for both halves, windward elevations up to these heights and leeward descents, even though they are not always pure dry-adiabatic, are generally common, so that the ideal foehn process can be demonstrated not only theoretically, but also by recordings.

But simply the fact that, even on overcast days, the leeward heat increase and the valley/slope temperature gradient is largest between 11 and 16 hours, as well as the fact that the nightly valley inversion within the cross section of the valley very often remains, indicate that at least in the summer months the daily effects of the valleys never entirely vanish, and must always be taken into account in the estimation of the degree of the foehn effects.

It is thus obvious that, disregarding generally overcast days both windward and leeward, usually rich in winter precipitation and with a low condensation level, in the Central Mountains the cloud build-up of the lee, and less often the cloud dissipation at the lee, principally represents the cause of the leeward heat excess. This is therefore a secondary phenomenon of the cloud cover effect; but it is this which creates the thermal preferment of the lee side in the hourly and daily mean, as well as the monthly and yearly mean. The great preponderance of SW-winds in Central Europe is ultimately manifested in the long-term climatic coefficient of the stations of the foreland and northern margin of the Thuringian Mountains.

The scale of the cloud patterns, the alterations of which are clearly due to the influence of the Central Mountains, and which produce the heat excess of the lee, is very broad and embraces - often in purely classical shapes - all the varieties

of windward-piled fair-weather cumuli above the fog congestion of the southern side, the enclosed stcu and cu banks at the crest, and otherwise cloudless weather, until the lower and middle cloud levels are dissipated and leave behind a precipitation; there are also foehn gaps in the as, sometimes higher, as well as moazagotl-like obstruction clouds with foehn walls over the mountains (Fig. 12). The peculiarity of this phenomenon is that all possible weather conditions, so long as they have a wind component not parallel to the range and a somewhat low condensation level, can produce foehn effects.

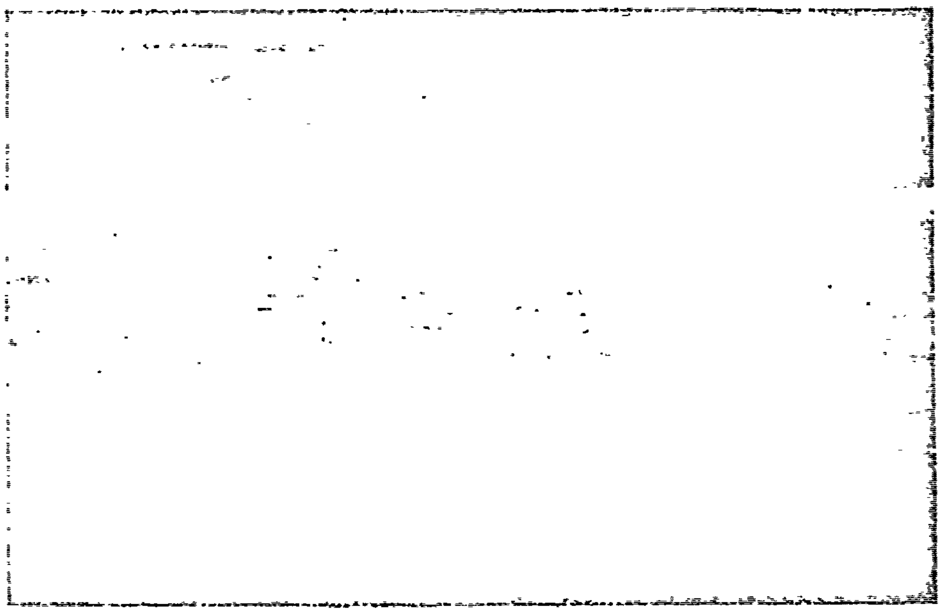

Fig. 12. Foehn walls and high obstruction clouds above the Central Thuringian Forest, seen from Tannroda on 24/10/1954 at 13 hours. Backlighted photo. Phot. Verf.

Of special frequency and persistence are post-cold frontal weather conditions at the transitional seasons and in the winter with southwest wind, when under an otherwise cloudless sky at the upper boundary of the ground layer there are formed low convection cumuli, which only cover several tenths of the sky, but at the southern rim of the mountains, as a consequence of a

slight upwards component, these are fortified and piled up into a massive cloud fringe. The instability of the humidity in this case obtains only in the ground layer; in the cold air flowing above, there prevails a dryness, good visibility, and few clouds. From the clear northern side of the mountains, usually free of clouds, a view to the south reveals a long, very low, massive foehn wall along the mountain crest, which rises during the day as the convection intensifies, sometimes washing over to the lee side and dispatching turbulence cumuli to the north. All of the crests and summits, as well as the entire southern half of the mountain down to 400-800 m, are veiled in a dense, drifting fog, often with heavy drizzling, while at the same time the foreland further south is itself free of clouds.

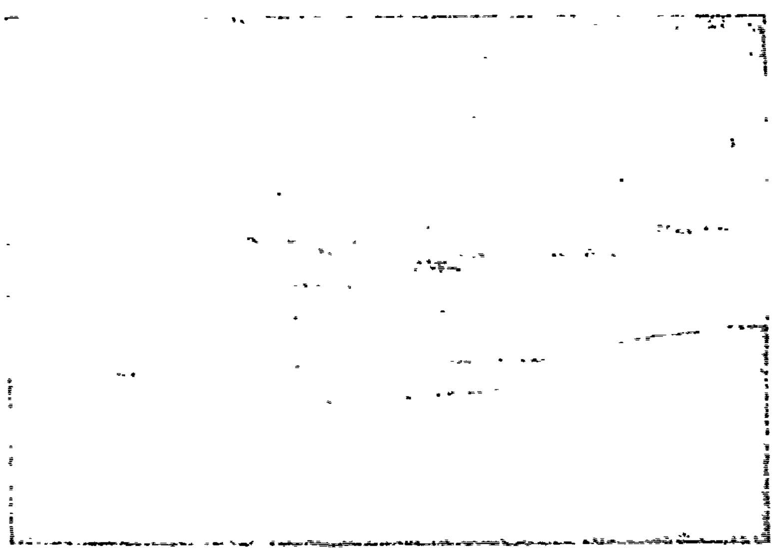

Fig. 13. Intensified Cu-formation at the SW side of the Central Thuringian Forest (right), cloudlessness to the north of the Rennsteig (left in the picture). View from Eckardtskopf near Oberhof in the SE direction, in the foreground Gehlberg, on 22/8/1958. Phot. W. Hickel

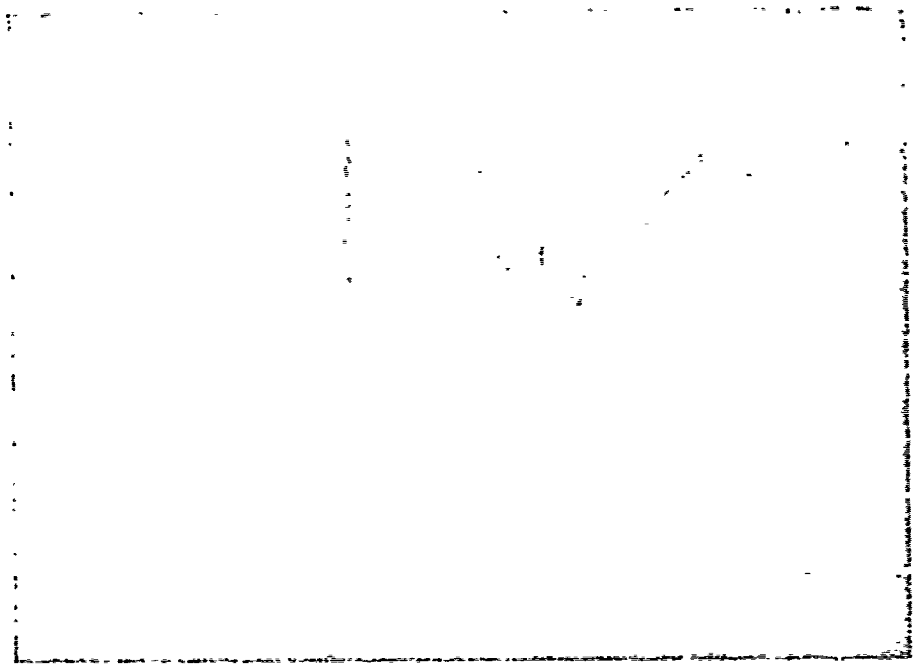

Fig. 14. Foehn gaps in the as at the northern rim of the Thuringian schist mountains at Saalfeld - Bad Blankenburg, taken under light rain from the roof of the university observatory at Jena on 3/11/1953, 11 hours. Phot. Verf.

For an anticyclonal northern situation, the opposite development may also be observed: on otherwise cloudless days with NE-wind, early in the morning, cumuli increase from the vapor of the valley inversion with the heating which begins at the northern margin of the mountains up to a slight distance over the crest, and a closed chain of soon-redissolving cloud pillars is formed.

But also on summer days with slight southern wind, which display a pronounced fair weather aspect and a high Cu-condensation level, an intensified convection and abrupt interruption of the latter beyond the crest are distinctly noticed in the different cumulus patterns of both halves of the mountains (Fig. 13). In this case, the northern half of the mountains and the foreland remain nearly free of clouds. From this vantage point, fre-

quently in the southern direction a view of a continuous Cu-chain above the crest is granted.

The cloud patterns during warm front passages are the most multifarious, as in the high mountains. Since there is merely a reduction in the intensity of precipitation at the lee during strong fronts, only light clearings in the lowest level over the lee side can be seen from this standpoint with great regularity (often also in the lee of isolated mountains, ridges, or plateaus), while the medium and high levels remain closed. But in the case of weaker fronts with light rain from as or high st there can be seen clearly from Jena, Weimar or Erfurt sharply indented silver strips (Fig. 14) on the entire range along the clearings, or even small blue gaps in the clouds at distances of 30 km or more. If it is only a matter of a medium-high pre-frontal updraft, the foehn gaps spread very much and often extend from the mountains to the above-named cities. In this situation, the foehn wall is often absent or only diffusely formed; for stronger warm fronts the edge of the low, mountain-veiling st-cloud cover is always distinctly expressed on the north side of prominent terrain levels. It is also interesting to follow several successive pressure buildups and lees within the mountain range, where it is broad and diversely staggered across the lengthwise direction; e.g., the southern halves and crests will be entirely enveloped in rain and clouds, but the first leeward northern slopes are free of clouds from the foehn effects, while the next leeward southern slopes experience a secondary pressure buildup and rain etc., until finally the third or fourth mountain ridge to the North, parallel with the crest and equally as high, remains free of lower clouds and possibly also of rain.

The foehn phenomena are very generally more impressive in the Harz mountains, especially with respect to the lee effects, the high obstruction clouds, and the cloud dissipation to the

Fig. 15. Moazagotlart obstruction clouds over Quedlinburg, photographed toward the NE. Phot. L. Schulz.

northeast of the Brocken massif being even better developed than those of the Thuringian Mountains (Figs. 15 and 16).

6. Conclusions

In regard to the preceding discussion, it is not possible to use the vertical temperature gradient or the relative humidity as criteria for the existence, duration, and intensity of the orographic cyclonal foehn, in view of the low average height and the influences of the time of day, which cannot always be excluded, even on overcast days. Instead of the above, the temperature (and humidity) differences between leeward and

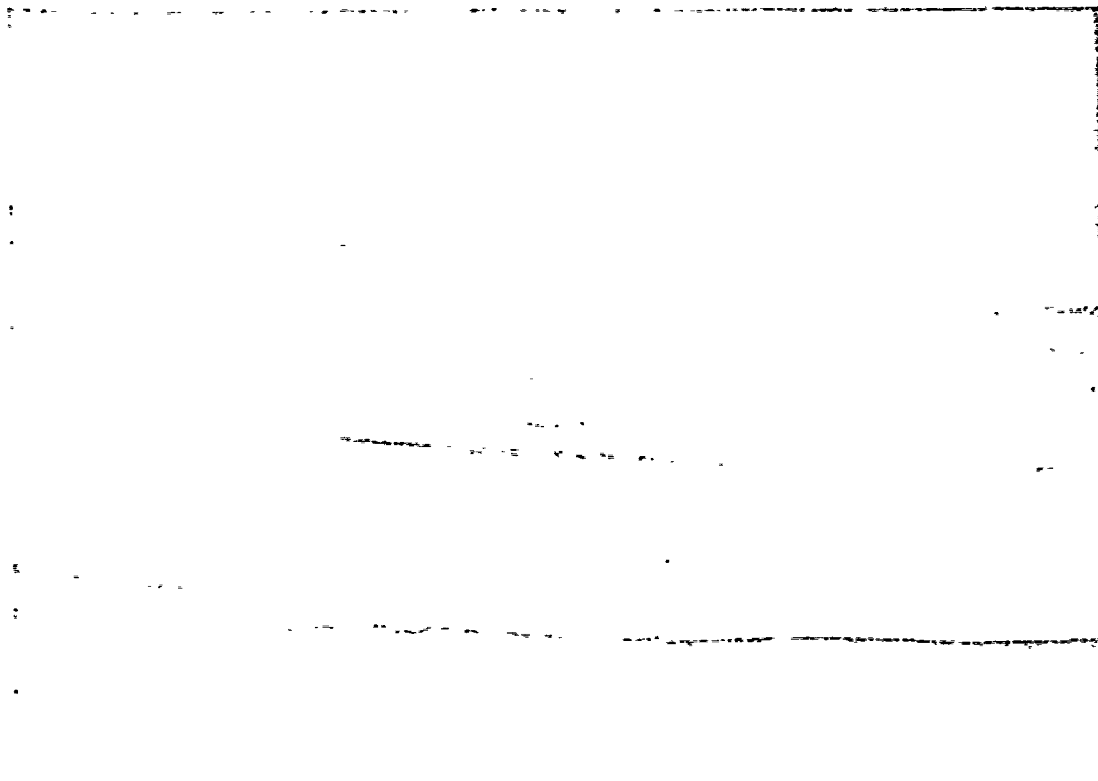

Fig. 16. Foehn gaps in the lee of the Harz Mountains at Quedlinburg at sunrise. Phot. L. Schulz.

windward stations of identical altitude have proved to be highly suitable as foehn criteria. Since the "fair weather effects" frequently set in rather intensively (radiative heat in the day, formation of inversions at night) in the case of a foehn, sometimes in the lee, but particularly in the dissipated cloud cover of the lee side, those again cannot be used without reservation, and should only be regarded as representative after an appraisal in relation to the latter. Steep upper slope situations in a poor-light northern exposure are most likely free of local effects and therefore best suited for the siting of comparative stations.

With the introduction of the temperature and humidity differences of both sides as foehn criteria, the category of foehn-active weather conditions in the Central Mountains is of course considerably enlarged, since cold air congestions or slightly unstable southern weather conditions form a large component, among others. This primarily pertains to the summer.

But the danger of including "false" or "foehn-like" situations or "transitional conditions" in the foehn statistics is a risk to all researchers of the high mountain foehn who employ, say, the wind direction, gustiness, a high temperature gradient or so forth as the principal criteria for statistical analyses. The "3-criteria characteristic" of Conrad [6], namely the wind direction from the mountains, the temperature increase, and the drop in the relative humidity, is also in no way capable, in the Central Mountains, as well as the Alps, of distinguishing a genuine "front" foehn from a (false) post-cold frontal weather "foehn" with south wind, according to the above experiences.

By virtue of its small meridional extent and its very good road facilities, the Central Mountain range offers the advantage (in the present case certainly dubious) of an easy monitoring of the weather processes by means of registrations, synoptical observations, and transit surveys, as well as the possibility of a thorough sorting and criticism of the diverse causative factors. In the Alps, the breadth and height of the mountains, the low density of stations, the absence of pairs of stations of identical sea-level and in many cases the presence of a national border hinder the necessary synoptical survey. Nor is it possible to decide as to the reality of a genuine foehn process by individual elements, a complex of causative factors, or the view of the sky from a station, no matter how impressive the weather events in the Alps; it is also very difficult to separate genuine and false foehns from each other, while again this is possible in the Central Mountains without difficulty.

It therefore appears feasible to transfer the data gathered in the Central Mountains with little difficulty to the Alps; it is better to slightly enlarge the category of foehn weather situations, than to make it too restrictive.

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